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Morphology and habitat properties of *Tortula lingulata* in Estonia

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Abstract: *Tortula lingulata* Lindb. is a moss that is rare in Europe and under protection in Estonia. It grows sparsely on sandstone outcrops. Eight localities are known in Estonia. Main morphological characters of the species and environmental parameters were measured at five sites. The moss shoots were longer at sites with higher sandstone moisture, and the nerve of the leaves was wider at sites with higher moisture and conductivity level under the moss patch.

Kokkuvõte: *Tortula lingulata* morfoloogia ja kasvukohatingimused Eestis

Keeljas keerik (*Tortula lingulata* Lindb.) on kogu Euroopas haruldane ning Eestis riikliku kaitse all olev samblaliik. Ta kasvab liivakivipaljanditel, Eestis on teada kaheksa leiukohta. Mõõdeti peamised liigi morfoloogilised tunnused ja kasvukohtade keskkonnaparameetrid. Sambla varre kõrgus osutus suuremaks kõrgema niiskustasemega liivakivil ja leheroo laius suurema niiskuse ja elektrijuhtivuse korral samblalaigu all.

INTRODUCTION

Bryophytes differ greatly in distribution and habitat range. Some species have restricted distribution or specific demands for habitat conditions, occurring only in certain types of communities or on specific substrata. Such selective species are usually more vulnerable to environmental changes and human influence, and are often included in red data lists (Standards and Petitions Working Group, 2006).

Tortula lingulata Lindb. is a species that grows only on sandstone outcrops (Frey et al., 2006). This species was first described at the end of the 19th century on the basis of material collected from sandstone denudation, territory of present Latvia (Lindberg, 1880; Ingerpuu & Vellak, 2007). Sandstone bedrock is distributed all over Europe; denudations can be found from Spain to Sweden. Nevertheless data concerning the distribution of *T. lingulata* is fragmentary. In Europe it is known to occur in Estonia (Ingerpuu et al., 1998), Latvia (Ābolina, 2002), Russia (Ignatov et al., 2006), Ukraine (Bachurina & Melnichuk, 1988), Georgia (Chikovani & Svanidze, 2004), the Czech Republic (Kučera & Váňa, 2003) and Germany (Meinunger & Schröder, 2007). There are also some doubtful records from Montenegro (Sabovljevic et al., 2004) and France (De Zuttere, 1993), where it is listed as *Tortula lingulata* var. *montenegrina* (Breidl. Szyszyl.) Broth. According to Corley et al. (1981), this name is a synonym for *T. lingulata*, while Košnar (2007) shows its closeness with *T. obtusifolia* (Schwägr.) Mathieu. In Asia it has been reported from Tadjikistan, where it surprisingly grows on limestone as well as on sandstone (Mamatkulov, 1975). We did not find any data for its occurrence in other parts of the world.

Tortula lingulata is included in the European Red Data Book as an insufficiently known species (ECCB, 1995), and it belongs to the red data lists of Estonia and Latvia. It is also protected by law in both countries.

Siliceous rocky slopes are considered to be important habitat types at the European level (EU Directive, 1992). A total of ca. 260 sandstone outcrops can be found in Estonia (Kleesment, 2001). They are concentrated in southern Estonia, where Devonian sandstone is denudated, whereas those from the Cambrian and Ordovician age occur in northern Estonia (Rõõmusoks, 1983). In the total distribution area, *T. lingulata* appears to be the most frequent in Estonia and Latvia, where it is known according to herbaria data from eight and seven localities, respectively (Ābolina, 1968; Košnar, 2007). In the Czech Republic it has been found in only two localities (Košnar, 2007), in Germany in one locality in Baden-Württemberg state (Meinunger & Schröder, 2007). The number of localities in Russia, Ukraine and Georgia is unknown. The distribution of *T. lingulata* according to present knowledge is very scattered, comprising central and eastern part of Europe.

The aims of this study are to specify the habitat requirements of *T. lingulata* in Estonia and to determine whether there are any relationships between local environmental conditions and plant morphological variation.

MATERIAL AND METHODS

Material was collected and the environmental measurements were taken at five of the eight known localities of *T. lingulata* in Estonia (Fig. 1) in the summer of 2007. These five localities are distributed in the southern part of Estonia, between 58°29'N and 57°45'N; 24°49'E and 27°23'E, the distance between the sites is 25–180 km. The mean annual temperature of this region was 6.7 °C in 2006 and 6.9 °C in 2007, and annual precipitation was 605 mm in 2006 and 660 mm in 2007. The number of days with precipitation was 107 in 2006 and 138 in 2007. The climate of these years was exceptionally warm and relatively dry since the mean annual temperature for 32 years (1966–1998) was 5.5 °C, and the mean annual precipitation 700 mm (Jaagus, 1999).

In order not to harm the populations of this national protected species, only 10 shoots were collected from each site. At all localities the inclination of the sandstone below the moss patch in degrees from vertical level and the direction according to compass were measured. In addition, three close measurements (about 5–10 cm apart from each other) were done and means calculated for 1) moisture % below the moss patch and beside the moss patch (measured with Exotek HUMITEST BDD moisture detector); 2) the illumination on the moss patch and in the open area (measured with Velleman light meter DVM1300); 3) the number of shoots per 1 cm^2; 4) depth of brittle sandstone below and beside the moss patch (by penetration with a metal rod of 1 mm diameter up to resistance). Sandstone samples were collected for pH and conductivity measurements. The sandstone samples were mixed with distilled water (1:10) and kept for 24 hours before pH measurements. For conductivity measurements the sandstone samples were kept for 0.5 hours mixed with distilled water (1:5). The reaction was measured with a Lutron PH 212 pH meter and the conductivity with a WTW Cond 315i/SET.

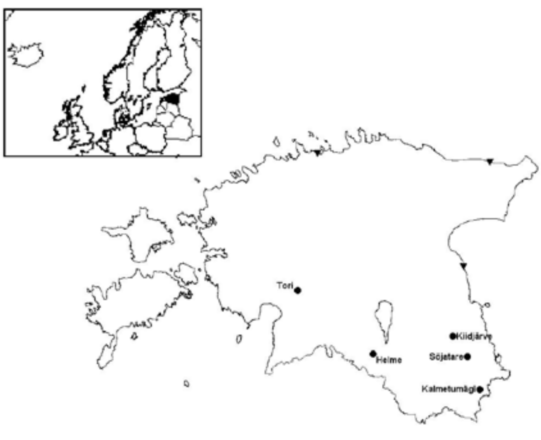

Fig. 1. Localities (all marks) of *Tortula lingulata* Lindb. in Estonia. ● – studied localities.

The total length and length of the rhizoid-covered part of each shoot was measured (n=50). Three leaves from the median part of each shoot were detached. Leaf length and width, median leaf cell length and width, the length of the leaf's basal part (with hyaline cells), basal cell length and width (in middle part between leaf margin and nerve), nerve cell length and width (in middle part of leaf and nerve), and nerve width in the basal part were measured, and means per shoot calculated. In addition, length of seta, length and width of ripe capsules (covered with operculum) from two localities (n=13) and diameter of spores from one locality and five capsules (n=50) were measured.

Spearman Rank correlation was used to find correlations between morphological characters (n=50), and between the environmental parameters together with shoot density (n=5). One-way ANOVA was used to study the influence of locality on the morphological characters, comparisons were tested with the contrasts for LS means. The morphological characters were tested for normality before analysis. All analysis were done with Statistica 6.0 (STATSOFT INC., 2001). Due to the rarity of the species the number of measurements for environmental variables remained very small (n=5), although ca. two thirds of all known localities were studied. Therefore it is not proper to use statistical methods for studying the influence of environmental parameters on morphological characters and we can only point to certain trends discovered by comparing graphically means of morphological and environmental variables.

RESULTS

Tortula lingulata grew in almost pure patches. Single shoots of *Gyroweisia tenuis* (Hedw.) Schimp., *Leptobryum pyriforme* (Hedw.) Wilson, *Barbula unguiculata* Hedw., *Hypnum cupressiforme* Hedw. and *Bryum* sp. were growing mixed with *T. lingulata,* one or two species per patch.

The exposition of the moss patches in the studied localities was to the north, north-west (2 localities), west and south-west.

Mean shoot density per 1 cm^2 was 30 ± 10 (n=15; min 17, max 60).

Archegonia were present at all localities, antheridia at two localities, and capsules were registered at two localities.

Morphometrical measures are presented in Table 1. The shoot length of *T. lingulata* varies between 1.03–2.5 mm, leaf length between 0.13–0.88 mm, cell length between 14–36 µm, cell width between 8–15 µm. The diameter of a spore varies between 10–20 µm.

Shoot length was significantly positively correlated with the length of the rhizoid covered part, leaf length, leaf width, length of leaf basal part and nerve width. Length and width of leaf, those of middle leaf cells, and basal cells were significantly positively correlated, but those of nerve cells were significantly negatively correlated (Table 2.)

Environmental measures are presented in Table 3. Moisture below the moss patch was higher than that of the sandstone beside the moss patch. The layer of the brittle part of the sandstone was a bit deeper under the moss patch. Illumination just over the moss patch was only 1.4–4.5 % of the open area illumination. The pH of the sandstone was more or less neutral. Conductivity was lower under the moss patch.

There were very few significant ($p<0.05$) correlations between environmental factors: moisture below moss patch was positively correlated with pH (R=0.9), conductivity (R=0.97) below moss patch, and shoot density (R=0.9).

According to the comparisons shoot length, rhizoid-covered part of shoot length, and height of basal part of leaf could be associated with moisture % beside the moss patch (sandstone moisture). The most easily measurable character is shoot length (Fig. 2). Nerve width could be associated with the moisture % below moss patch (Fig. 3) and conductivity. The variation of the nerve width pattern differed from the shoot length variation pattern. The factor 'location' affected the shoot length significantly ($F= 14.1$, $p < 0.0001$), but not the width of nerve, although the locations with minimum and maximum mean nerve width values differed significantly from each other.

Table 1. Morphometrical parameters of *Tortula lingulata* Lindb. in Estonia. Variables of gametophyte from 5 localities: shoot variables n=50; leaf and cell variables n=150, variables of sporophyte from two localities, n=13; spores from one locality, n=50.

Variable	Mean	Minimum	Maximum	Std. Dev.
Shoot length (mm)	1.75	1.03	2.5	0.41
Rhizoid-covered shoot length (mm)	0.38	0.13	0.88	0.16
Leaf length (µm)	964	650	1317	151
Leaf width (µm)	340	243	523	63
Length of basal part of leaf (µm)	160	53	370	77
Median cell length (µm)	21	14	36	4
Median cell width (µm)	11	8	15	1
Nerve cell length (µm)	53	27	98	12
Nerve cell width (µm)	6	2.5	12.5	2
Basal cell length (µm)	43	32.5	67	8
Basal cell width (µm)	15	11	22.5	2
Nerve width (µm)	48	37	62	6
Seta length (mm)	5.91	3.75	9.13	1.47
Capsule length (mm)	1.47	0.95	2.25	0.38
Capsule width (mm)	0.6	0.42	0.75	0.08
Spore diameter (µm)	13.3	10	20	1.71

Table 2. Spearman rank correlations between the morphological characters of *Tortula lingulata* Lindb. N = 50; bold numbers – significant correlations at $p < 0.05$; ns – not significant.

	1	2	3	4	5	6	7	8	9	10	11	12
1 Shoot length	1											
2 Rhizoid-covered shoot length	**0.77**	1										
3 Leaf length	**0.67**	**0.49**	1									
4 Leaf width	**0.50**	**0.29**	**0.60**	1								
5 Length of basal part of leaf	**0.63**	**0.48**	**0.71**	ns	1							
6 Median cell length	ns	ns	ns	ns	ns	1						
7 Median cell width	ns	ns	ns	ns	ns	**0.41**	1					
8 Nerve cell length	ns	ns	ns	ns	ns	ns	ns	1				
9 Nerve cell width	ns	ns	ns	ns	ns	ns	ns	**-0.35**	1			
10 Basal cell length	ns	ns	ns	ns	**0.45**	ns	ns	**0.36**	ns	1		
11 Basal cell width	ns	ns	ns	ns	**0.37**	ns	ns	**0.9**	ns	**0.46**	1	
12 Nerve width	**0.46**	ns	**0.55**	**0.55**	**0.28**	ns	ns	ns	**0.30**	**0.28**	ns	1

Table 3. Environmental variables at five localities of *Tortula lingulata* Lindb. in Estonia, n=15.

Variable	Mean	Minimum	Maximum	Std. Dev.
Moisture (%) below moss	43.8	26.6	57.7	10.5
Moisture (%) beside moss	23.9	13.8	42.2	10.1
Brittle sandstone depth below moss (mm)	1.07	0	3.33	1.23
Brittle sandstone depth beside moss (mm)	0.93	0	2.33	0.81
Illumination (% of open area illumination)	2.6	1.4	4.5	1.1
pH	6.97	6.12	7.77	0.66
Conductivity below moss ($\mu S\ cm^{-1}$)	257.1	82.7	400	129.5
Conductivity beside moss ($\mu S\ cm^{-1}$)	617.4	155	1690	556.9
Sandstone slope (degree from vertical)	25	10	45	13.2

DISCUSSION

The values of the morphological characteristics of Estonian populations differ somewhat from those reported in several floras. The shoot length measured by us (up to 2.5 mm) was generally shorter than that reported in other descriptions: up to 3 mm (Savitch-Ljubitskaja & Smirnova, 1970; Ignatov & Ignatova, 2003), up to 5 mm (Frey et al., 2006) and up to 6 mm (Košnar 2007). The leaf length was almost the same as that given by other studies, but the leaf width was about 40% less than that given by Ignatov & Ignatova (2003) and Košnar (2007). In addition, the width of the nerve was about 20% less than that reported by Košnar (2007).

The measurements of sporophytes and spores more or less coincided with those provided in the literature (Lindberg, 1880; Roth, 1904; Savitch-Ljubitskaja & Smirnova, 1970; Košnar, 2007); only the length of the capsule is reported to be longer by Ignatov & Ignatova (2003).

The archegonia were found to be present everywhere, but antheridia only at two sites; we did not find antheridia and archegonia on the same shoot. The species is dioecious according to S. O. Lindberg, but N. Malta (1926) mentions that it is autoicous. The sexuality of this species needs further studies.

The pH range for *T. lingulata* in Estonian localities was similar to those reported from Latvia (5.9–7.5; Apinis & Lacis, 1936).

T. lingulata grows on steep and hard sandstone outcrops. Such harsh habitat conditions must reduce the number of potential competi-

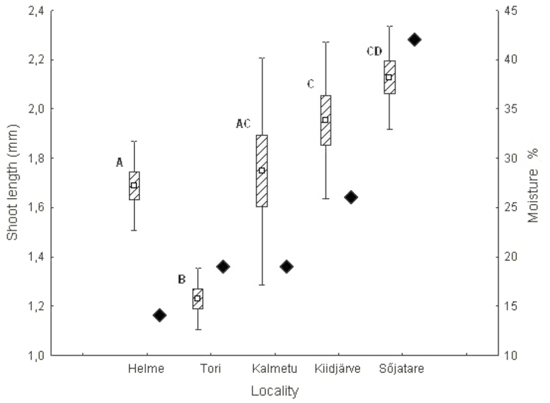

Fig. 2. Shoot length of *Tortula lingulata* Lindb. (striped boxes) and moisture % of sandstone beside moss patch (black diamonds) at different localities. Significant differences in shoot length ($p<0.05$) are marked with different letters.

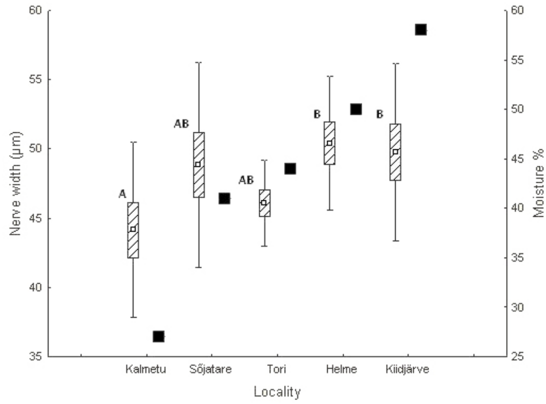

Fig. 3. Nerve width of *Tortula lingulata* Lindb. (striped boxes) and moisture % under moss patch (black boxes) at different localities. Significant differences in nerve width ($p<0.05$) are marked with different letters.

tors. Indeed, very few other bryophytes, and no vascular plants grow between or just beside the shoots of *T. lingulata.* The species is very shade tolerant; moreover, it presumably needs shade to reduce the speed of drying out. The exposition of the species (mainly north and west) apparently serves the same purpose. Habitats in Estonia could be relatively dry, maybe due to exceptionally dry and warm recent years, since the plants in our study were shorter than reported from other studies. In our study the shoots of the species were longer at sites with higher sandstone moisture. High humidity is presumably achieved through favourable relief around the moss patch that allows to obtain more rain and surface flow water that brings also more nutrients and thus promotes the growth leading to the enlargement of a whole plant (shoot, leaves and cells).

The presence of *T. lingulata* patches on sandstone raises the moisture and lowers the conductivity of the uppermost layer of sandstone below the moss. This comes apparently from the evaporation inhibition and ion uptake by the moss patch. Moisture was higher under moss patches with higher shoot density. The width of the nerve is positively associated moisture and conductivity just below the moss patch. This relationship is difficult to explain, but as nerve should help to conduct water towards the leaf tip, higher water availability under moss patch might promote the lateral growth of nerve.

This study presents statistically unsupported trends of the influence of the environmental factors on morphological characters. It is almost impossible to gather the amount of data required for sound statistical analysis for rare and protected species in the field. Thus growing from spores and laboratory experiments could give better support to the discovered relations.

Regarding the relative rarity of *T. lingulata* in Europe, Estonia has the responsibility to save the known habitats of the species on its territory. The species belongs at present to the third category of protected species, which enables to protect only 10% of the known habitats (Looduskaitseseadus, 2004). To assure the protection of all habitats, the species should belong to the first category.

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